Improvement of imaging properties by optimizing the mask structure using phase shift effect

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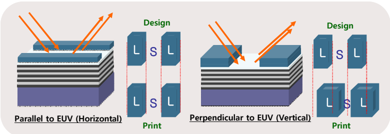
Introduction

What is EUV Lithography ?

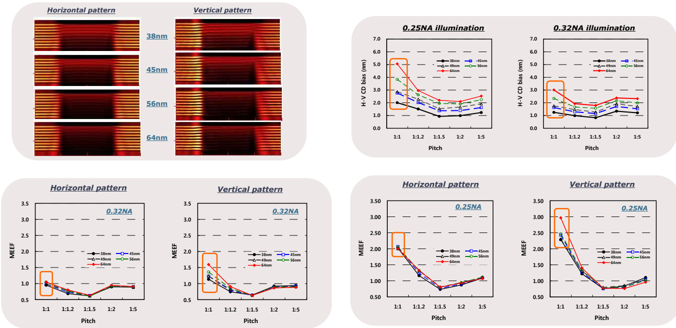
Extreme ultra violet lithography (EUVL) using 13.5 nm wavelength is expected to be the mainstream of production process for 22 nm half pitch and below. Mask shadowing is a unique phenomenon caused by using a multilayer mirror-based mask with an oblique incident angle of light. Reducing the absorber thickness is the most effective method to minimize a mask shadowing effect. A phase shift concept is a potential solution to improve the image contrast with a thinner absorber stack. The mask structure used in this study consists of an absorber, phase shift layer and a capping layer on the 40 pair of Mo-Si multilayer. Thickness and reflectivity on the absorber stack could be controlled with maintaining the out-of phase condition.

What is the mask shadowing effect?

- The illumination beam is shadowed by the edge of the absorber.
  → The effective mask CD is changed. → Printed pattern shifted and biased.
- Correction for shadowing effect should be considered.
  → Rule-based OPC works?

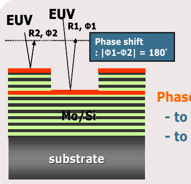


Effect of absorber thickness on mask shadowing effect



- Asymmetry of EM field and H-V bias are affected by absorber thickness and resolution.
- MEEF of vertical pattern increases with absorber thickness, especially at dense pattern.

Phase shift mask in EUVL



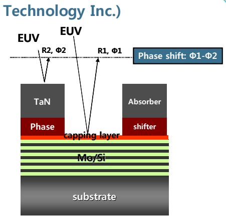
Phase shift concept?
- to improve image contrast
- to reduce absorber stack thickness

- Reducing the absorber stack thickness is the best way to minimize the mask shadowing effect.
- How to reduce absorber stack thickness maintaining high image contrast?
- What is the main factor to control the phase shift?
  → The structure of capping layer is one of the main factor to influence the phase shift.
  → The optimization of capping structure is needed.

The condition of aerial image simulation

- Simulator: EM-SuiteTM (Panoramic Technology Inc.)
- Simulation condition

Parameter	Value
Wavelength	13.5nm
NA	0.25, 0.32
Magnification factor	4
sigma	0.6
Incident angle	6˚
Pattern width	22nm 1:1 L/S



- Mask structure

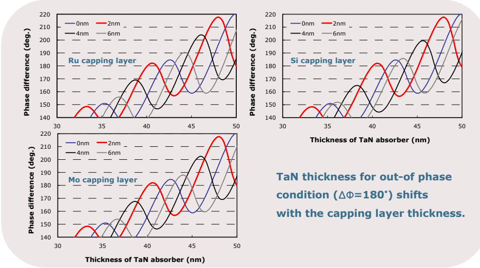
Structure	Absorber stack thickness (nm)
TaN/capping structure/ML	40.5nm

Material	n (1-δ)	k (β)
TaN	0.92699	0.04363
Si	0.99900	0.00183
Mo	0.92388	0.00643
Ru	0.88635	0.01709

- Mo shows the similar δ value with TaN absorber, where as, Mo shows the lower β value than TaN absorber.

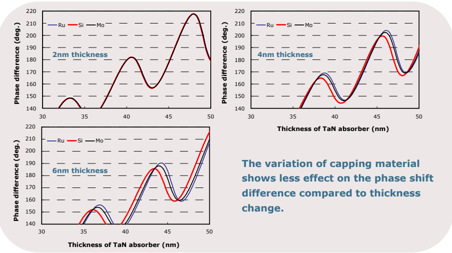
The results of aerial image simulation

Phase difference as a function of TaN absorber and capping layer thickness



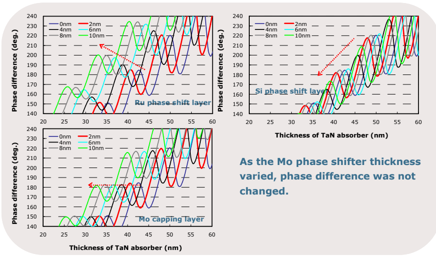
TaN thickness for out-of phase condition (ΔΦ=180˚) shifts with the capping layer thickness.

Phase difference as a function of TaN absorber and capping layer material



The variation of capping material shows less effect on the phase shift difference compared to thickness change.

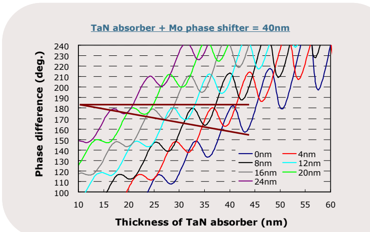
Phase difference as a function of TaN absorber and phase shift layer thickness



As the Mo phase shifter thickness varied, phase difference was not changed.

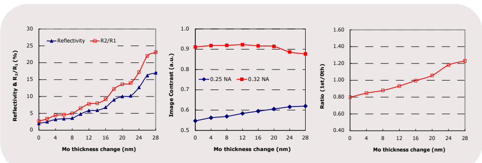
- The direction of phase difference shift related with δ value of phase shift layer .

Phase difference as a function of TaN absorber and Mo phase shift layer thickness



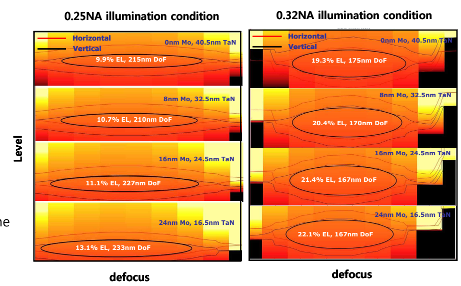
- The out of phase condition was achieved at the ~40nm absorber stack (absorber + phase shifter) thickness.
- As the Mo thickness increased, TaN absorber thickness latitude increased.

Reflectivity, $1_{st}/0^{th}$ spectrum ratio and image contrast with Mo phase shifter thickness



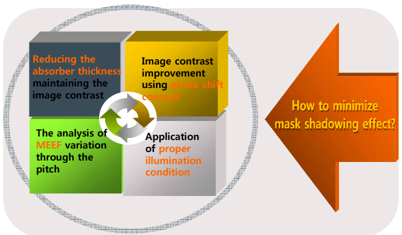
- As the Mo phase shifter thickness increases, reflectivity from the absorber stack increases.
- However, the image contrast did not decrease.
- As the Mo thickness increased, $1^{st}/0^{th}$ spectrum ratio increases

H-V overlapping PW for 22nm L/S patterns depending on Mo phase shifter thickness



Summary

Optimized absorber structure and process condition



Acknowledgements

This work was supported by the EUVL R&D research fund of Ministry of Knowledge Economy, the Research fund of HYU and the scholarship program of Hynix Semiconductor. The authors would like to thank staff of Pohang Accelerator laboratory for their technical supports.